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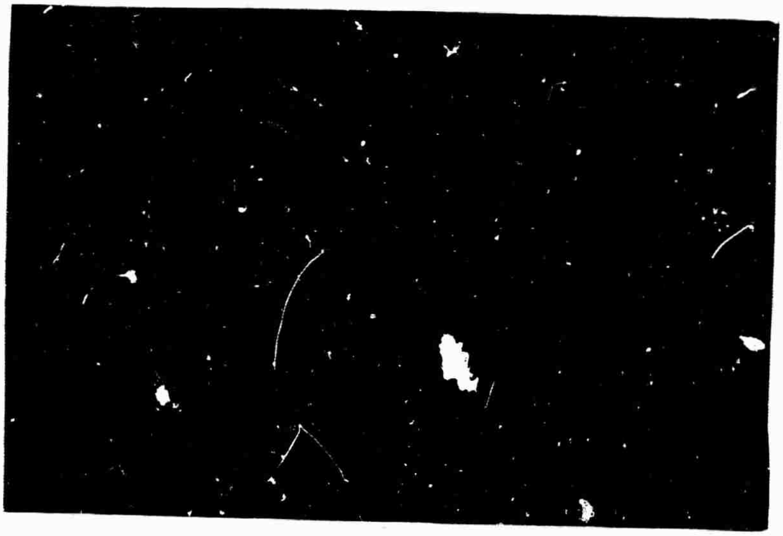

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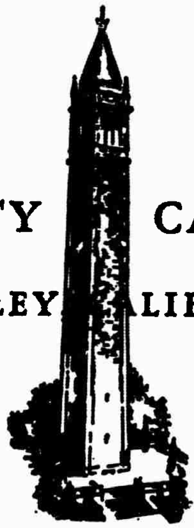

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ANNUAL REPORT, JANUARY 1 - DECEMBER 31, 1967

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ANNUAL REPORT - AFOSR

THE CENTRAL CALIFORNIAN LARGE-SCALE ARRAY

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1. Introduction.

Two lines of research using the UC telemetered network of seismographs have developed especially well in 1967. The first is the derivation of focal mechanisms of many small local earthquakes in order to throw light on the regional tectonic stresses. The second is the computation of $dt/d\Delta$ for S waves across the array and its variation with azimuth.

Both these studies are providing novel observational results; in neither case has more than a start been made on the theoretical and inferential aspects. From the point of view of discrimination between small earthquakes and underground explosions of comparable size, certain tentative conclusions can be adduced.

The fault-plane work using first motion P polarities mainly now includes some 25 earthquakes of magnitude 4.0 to 5.5. It plainly shows the great extent of regional uniformity and persistence of patterns of dilatations and compressions which may be possessed by small shallow focus earthquakes. The agreement between the observed fault-strike and the calculated one is usually so close when special care is taken in recording and reading the seismograms, that even variations in the strikes of the San Andreas, Hayward or Calaveras faults may be detected. The expectation is that this domination of the regional stress pattern on earthquake mechanism will be found worldwide. Indeed, it has already been demonstrated by L. Sykes, for example, that this is also the case for mid-oceanic ridges.

The work with S waves is being carried out for sources at both near and teleseismic distances. From distant earthquakes the array does record portions of the S wave trains which are coherent but the arrival times are later by 3 sec or so than predicted by the Jeffreys-Bullen tables. This would make S difficult to use at present in precise epicentral determinations. Also, we have detected and measured a large azimuthal variation in the slowness of S, $dT/d\Delta$, across the array. This variation is larger than had been measured for P propagation across the Berkeley or LASA arrays, for example.

During 1967, the network of 10 telemetry stations has been kept in continuous operation. To improve recordings of S waves, Willmore MKII horizontal-component seismometers, set at a free-period of 3 sec, have been placed in the telemetry network at Berkeley (BRK), San Andreas Geophysical Observatory (SAO), Pilarcitos Creek (PCC), Paraiso (PRS) and Mt. Hamilton (MHC). As a seismological observatory, the seismonet has continued to play a leading role in the location of California earthquakes and larger earthquakes elsewhere. Readings, seismograms and other information are provided regularly (and quickly if necessary) to a number of Federal, State and private agencies and research groups, including those in universities.

It is planned, using funds from a number of sources, to extend the telemetry links to the Mineral (MIN) and Arcata (ARC) stations in June, 1968. Both stations will be resited to allow more sensitive recording. The array then will extend over a distance of 550 km from Priest (PRI) to Arcata (ARC) in Humboldt County.

2.1 Seismicity and Tectonics.

During the past year much progress has been made in the investigation of details of seismicity and focal mechanisms. Tectonic implications are now becoming clear of the relationship between these two parameters for earthquakes in central and northern California, including the complex oceanic structural systems of the Mendocino Escarpment and Gorda Ridge.

The systematic study was made possible by the presence of the Berkeley array since 1962. The first step was the precise determination of the distribution of epicenters and their relation to the tectonic features of the area; an investigation followed of regional stress patterns as revealed by fault-plane solutions obtained for some 25 earthquakes in locations ranging from the Parkfield area south of the array to the vicinity of the Parks Seamount about 400 km off the Oregon coast.

Inferences follow from these studies regarding the pattern of stress distribution throughout the Coast Ranges of central and northern California and the transition into the complex offshore structure along and north of the Mendocino escarpment. In addition, some insight is given into the tectonic significance of seismically inactive, presumably "locked", zones along the region. Short-period P waves are used so that each seismogram must be read with uniform care. A lengthy paper will soon be completed. Some tentative results are summarized here.

Seismicity. With the installation of the Berkeley array, detection and location of earthquakes in central California became complete for events of magnitude greater than about 2.0. Based on seismicity catalogues thus provided from the array, an epicenter map has been prepared for the period January 1962 through June 1965 on a scale sufficient to show details of the relationship of earthquakes and fault structure. The map shows earthquakes of magnitudes above 2.5 superimposed on a fault map, the epicenter color-keyed for magnitude range. A second seismicity map of this type has been prepared for the northern California, Mendocino Escarpment, Gorda Ridge region. In the case of earthquakes far offshore, along the Gorda Ridge, locations are complete only for earthquakes of magnitude over about 3.5.

Both these maps will be incorporated as plates in the forthcoming paper describing the work on seismological evidence and tectonics of central and northern California.

In central California, the greatest levels of seismic activity occur in two zones along the San Andreas fault south of the Bay area. Both zones are elongated, the most intense concentration of epicenters falling in patterns about 20 km in length parallel to and some 5-10 km southwest of the San Andreas trace. These two active areas, near San Juan Bautista and Bear Valley, are separated by a 20 km stretch of relatively low seismicity. The two regions are near the intersection of the San Andreas and Calaveras fault systems.

Zones of minor clustering of earthquakes in the central California Coast Ranges occur in the San Francisco Bay area, on all three major transcurrent faults: Calaveras, Hayward, and San Andreas. Another center of activity lies near Mt. Hamilton, at the Hayward-Calaveras fault bifurcation.

Outside these four areas of relatively high activity the general background level of seismicity is rather uniform throughout the Coast Ranges, with two notable exceptions. These are anomalously quiet segments of the San Andreas north and south of San Francisco. Along the San Andreas from Pt. Arena southeastward to San Juan Bautista, the only area currently exhibiting activity is a short stretch offshore and southwest of San Francisco, near the epicenter of the large 1957 earthquake and perhaps, as recent work of Bolt has shown, the epicenter of the great 1906 quake.

In northern California and offshore, the major seismic activity is concentrated on the Gorda Escarpment (the prominent north-facing, east-west trending escarpment on the shelf off Cape Mendocino which to the west becomes the south-facing Mendocino escarpment) and adjacent land area of Cape Mendocino. This active zone, about 100 km long, is comparable in area to the combined San Juan Bautista and Bear Valley areas in central California, but produces earthquakes in the magnitude range above 4 at two to three times the rate in central California.

Earthquakes occur westward along the Mendocino Escarpment to longitude 127°.5 W, the intersection with the Gorda Ridge; they then follow the eastern rise (Escanaba Ridge) of the broad Gorda Ridge north-northeastward. There is also a scattering of epicenters in the low region between the Gorda Ridge and continental shelf. Moderately large earthquakes have occurred along the coast north of Cape Mendocino, west of Arcata and Crescent City. Activity in the Coast Ranges inland from Cape Mendocino is generally of the same level as in the region north of the Bay area. The submerged section of the San Andreas fault from Pt. Arena north to Shelter Cove is, as south of Pt. Arena, devoid of epicenters.

Tectonics. Fault plane solutions have been obtained for some 25 earthquakes on the San Andreas fault, Mendocino Escarpment, Gorda Ridge systems. The earthquakes are distributed from the Parkfield area on the San Andreas fault zone 300 km south of San Francisco to the vicinity of the Parker Seamount, some 400 km off the Oregon coast.

The stress pattern along the San Andreas, as evidenced from P-wave radiation patterns, is remarkably uniform from Parkfield to Cape Mendocino. With two exceptions, all the earthquakes analyzed indicate right-lateral transcurrent faulting as source mechanism. The strikesof the fault planes (selected by correlation with visible faulting) are almost perfectly consistent with mapped faults in the area. For example, the strike differences in the San Andreas, Hayward, and Calaveras faults in the Bay area are clearly evident in the fault plane solutions.

North of the Bay area, in the Coast Ranges, the fault orientations are consistent with extensions of the Calaveras-Hayward system. (The San Andreas is inactive at present north of San Francisco.) The two exceptions to the right-lateral motion characteristic of all other mechanisms in the Coast Ranges are of interest. These exceptions are either dip-slip motion on faults with the strike of the San Andreas and near the San Andreas trace, or else very low angle thrusts striking parallel to the continental margin, on the San Andreas. The interesting feature, however, is the opposite sense of the two mechanisms. One, the 1957 San Francisco earthquake, is very well determined as either a down-to-the-ocean dip-slip fault or else an ocean-over-continent thrust. On the other hand, off Pt. Arena, some 200 km north, the other exceptional mechanism, while less well determined, being a low-magnitude shock, seems to indicate either down-to-the-continent dip-slip or continent-over-ocean thrusting.

It should be noted that these anomalous focal mechanism solutions occur at the ends of one of the above-mentioned inactive zones of the San Andreas. It seems possible that the stability or "locked" nature of the San Andreas zone in this area is reflected in anomalous stress patterns at the ends of the zone.

North of the Bay area, in the Coast Ranges east of the quiet San Andreas trace, the focal mechanism solutions continue to indicate right-lateral slippage. In the Cape Mendocino area and north along the coast this is also true. However, the fault plane orientations become more westerly. It appears that significant right-lateral motion exists north of Cape Mendocino, possibly well into Oregon. The right-lateral pattern is maintained along the Mendocino Escarpment to the Gorda Ridge. However, the strikes of the fault planes, assumed from projection of the San Andreas, never coincide with the east-west orientation of the Escarpment, but maintain strikes of N60°W to N75°W.

On the Gorda Ridge focal mechanisms appear to be associated with normal faulting. This holds true to the north and then on northwesterly along the prominent lineament through Cascadia Gap. However, at the far northwest end of this feature, near the Parker Seamount, the focal mechanisms seem once again to be a right-lateral motion. It is interesting to speculate about the relationship of this region to the right lateral faulting off Crescent City. Ocean bottom topography gives strong indication that continuity may exist between the two areas, masked for a short segment in the Blanco Gap area. If, indeed, the transcurrent San Andreas type deformation is transferred to the feature containing the Parker Seamount, then the Gorda Ridge, Mendocino Escarpment system must be related to the stress patterns resulting from the termination of the persistent strike-slip motion just off Cape Mendocino--the "end"(?) of the San Andreas fault.

2.2 Teleseismic S-wave Detection.

In 1966, Otsuka showed that, for the Berkeley array, a systematic variation with azimuth existed in the azimuth anomaly A and the slowness anomaly S for P and pP waves at distances $30° < \Delta < 96°$. (Some intra-array distortion of the wave front was also detected. This feature was later observed also at LASA.)

As a further step in this work, these anomalies for S (and SKS) are being measured. In the first stage of the work, the measurements come from the three stations with horizontal component Willmore instruments, SAO, GCC and PRS. These stations form a tripartite net with base length 97 km and geometrical altitude (to SAO) 23 km. The use of identical recording systems at the three stations permits instrumental phase shifts to be ignored. Additional S recordings are available for comparison from the Berkeley horizontal-component seismographs with free periods of 30 sec; in one or two cases, the S waves were sufficiently energetic to show also on the telemetry develocorder traces from array stations with only Benioff vertical-component instruments.

Only eleven earthquakes, with $30° < \Delta < 100°$, from January to August, 1967, were found to provide adequate S wave-measurements for this study.

In Figure 2.1, the quality of the observational material is illustrated by a parallel play-out from the magnetic tapes of the S-wave trains from the

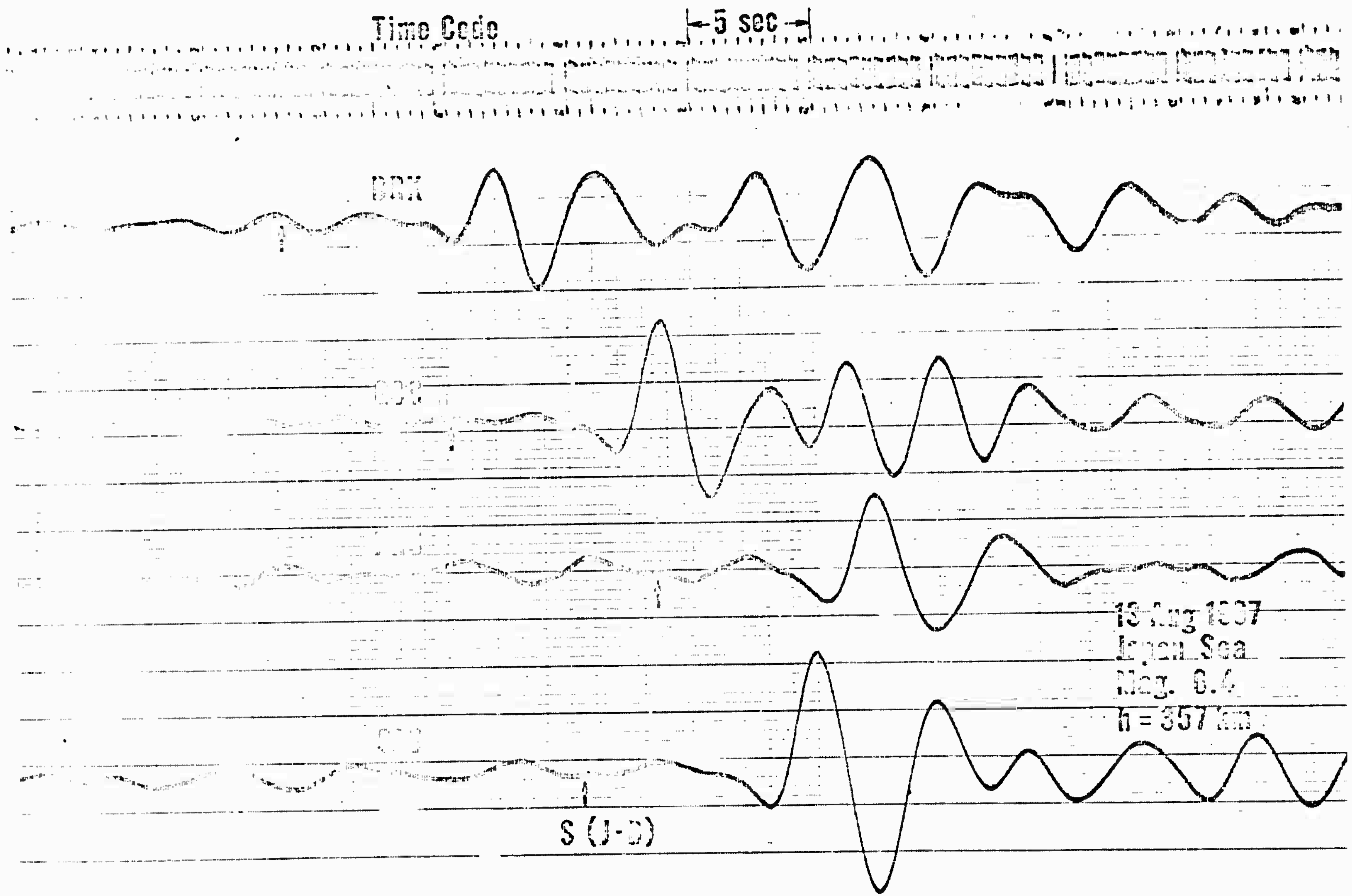


FIG 2.1

Japan Sea earthquake of August 13, 1967 which is 79° from SAO and has magnitude 6.4. Frequencies above 0.25 c/s have been attenuated by low-pass Kron-Hite filters for each signal. Only the form of the first cycle of S is repeated at each network element; the time interval between the first coherent large peaks can be read to 1/10 sec. The residual against the Jeffreys-Bullen tables for the S onset at SAO, on the adopted epicentral solution, is 5.5 sec; the corresponding P residual at SAO is 2 sec.

We do not observe that the degree of coherence in the S wave train at array stations varies strongly between earthquakes from different regions. Indeed, seldom does the S wave coherence between two of the stations BRK, SAO, PCC and PRS continue for more than one to two cycles. The clearest S trains were from the deep-focus earthquakes; signals were particularly clear from the shocks numbered 6, 10, and 11. Our analysis of the 11 earthquakes would support the conclusions of earlier workers that there is a distinct difference between the character of recorded S waves from shallow-focus and deep-focus earthquakes. Certainly, in the latter case, the signal-to-noise ratio, the sharpness of onset, and marginally, the coherence of the S trains, appears enhanced even for shocks of about the same magnitude. On this point, we were able to detect coherent S signals from the deep-focus earthquake in Argentina (No. 1) even though the magnitude was less than 5; unfortunately, this shock is at a distance just beyond the intersection of the S and SKS curves so that we place little reliance on the measured anomalies.

The predominant periods of the coherent S waves were between 4 and 7 sec at all four stations. The use of the Willmore instruments (T_o = 3 sec) strongly attenuates waves with periods exceeding 3-4 sec so that significantly longer periods in the recorded waves at SAO, PCC and PRS cannot be expected. However, the BRK recordings, from a system which does not begin strong attenuation until periods exceed 30 sec, demonstrate that little wave-energy is present above 6 sec, at least for earthquakes with magnitude near 6.5. The observed lack of coherence in S waves with wavelengths of order 20 km between stations of the order of 100 km apart, presumably entails structural differences in the crust under the stations.

There was a striking variation in the form of the early part of the S train between earthquakes; even with array-intra-correlation it was often extremely difficult to judge where the S waves first began. Most residuals exceed +3 sec although we always picked the onset <u>before</u> the first <u>clear</u> coherent peak or trough. For shocks numbered 3, 4, 5 and 8 (all shallow) the residuals are extremely large but we could detect no motion (above the noise) earlier on the records.

In 1942, Byerly drew attention to a smaller movement, which he called <u>the curtsey</u>, preceding the main movement of S. In our work we also often found a perceptible downward excursion (ground motion towards the northeast) lasting 3-4 sec before the first large excursion of the pendulum (see e.g., the SAO signal in Figure 2.1). This movement resembles a curtsey but it is of interest that, when the signal-to-noise ratio is particularly high, additional low-amplitude motion can be detected in the curtsey. For example, with shock 6, the SAO record shows a curtsey but this precursor to the large movements contains a small coherent peak on the BRK, PRS and CCC records.

The measured anomalies are shown in Figure 2.2 for the tripartite network. Of the plotted points, only those from shocks numbered 2, 3, 6, 7, 9, 10, 11 can be considered a uniform set. The measured signal from shock 1 is probably S but may contain SKS components; the first perceptible coherent waves in shock 5 arrive 23 sec after the time predicted by the Jeffreys-Bullen tables and may be PS. The waves from shock 8 are undoubtedly SKS.

The reliable points form two groups. The azimuth anomalies for shocks 3, 7 and 11 (N45°W) are consistent and those for shocks 4, 6, 9 (E20°S) agree. The first group show that azimuth anomalies in S of order 20° can occur as can slowness anomalies of 1 sec/deg.

The curve on Figure 2.2 represents the curve drawn by Otsuka for the crustal model with the dipping Mohorovicic discontinuity which gave the best fit to the observed P anomalies. Both P and S wavefronts propagating from northerly foci (Aleutians, Kuriles, Japan, etc.), parallel to the coast of central California, are bent towards the continent. In contrast, although P waves from South American earthquakes (Colombia, Bolivia, etc.) are also deflected towards the continent, the provisional results for S waves (based upon three earthquakes) indicate that S waves are deflected in the opposite sense (at least for the coherent portion of the train which was measured). The physical condition of the upper mantle under California is evidently such that the portions of the P and S waves which carry the principal energy do not always travel the same ray path.

2.3 S Waves from Near Earthquakes.

From a study of the S phase from local earthquakes, using both short- and long-period, horizontal and vertical, instruments of the Berkeley array, the following conclusions are outlined:

1) A clear impulsive S phase can usually be identified on horizontal instruments within 100 km of the epicenter. A particle motion study of S arrivals within this range indicates the motion to be roughly linear. The average S velocity in the Coast Ranges from earthquakes within 100 km, using epicenters calculated from P arrivals, is of the order of 3.5 km/sec. It has not yet been possible to compute a reliable travel-time curve for crustal S.

2) The S arrival from earthquakes at epicentral distances beyond about 100 km is hard to identify. S_n in particular is not easily recognized. Earthquakes from which S_n is observed usually lie north of the array, within or off the coast of northern California.

3) Examination of long-period waves recorded on magnetic tape at BRK shows that the Love wave has usually become well developed at distances on the order of 100 km. In many cases, this horizontal transverse component is the predominate ground motion recorded.

In the light of these observations, the nature of the S wave from local earthquakes in the array region, is not given to simple interpretation. We mention certain other observational and theoretical considerations which make interpretation difficult.

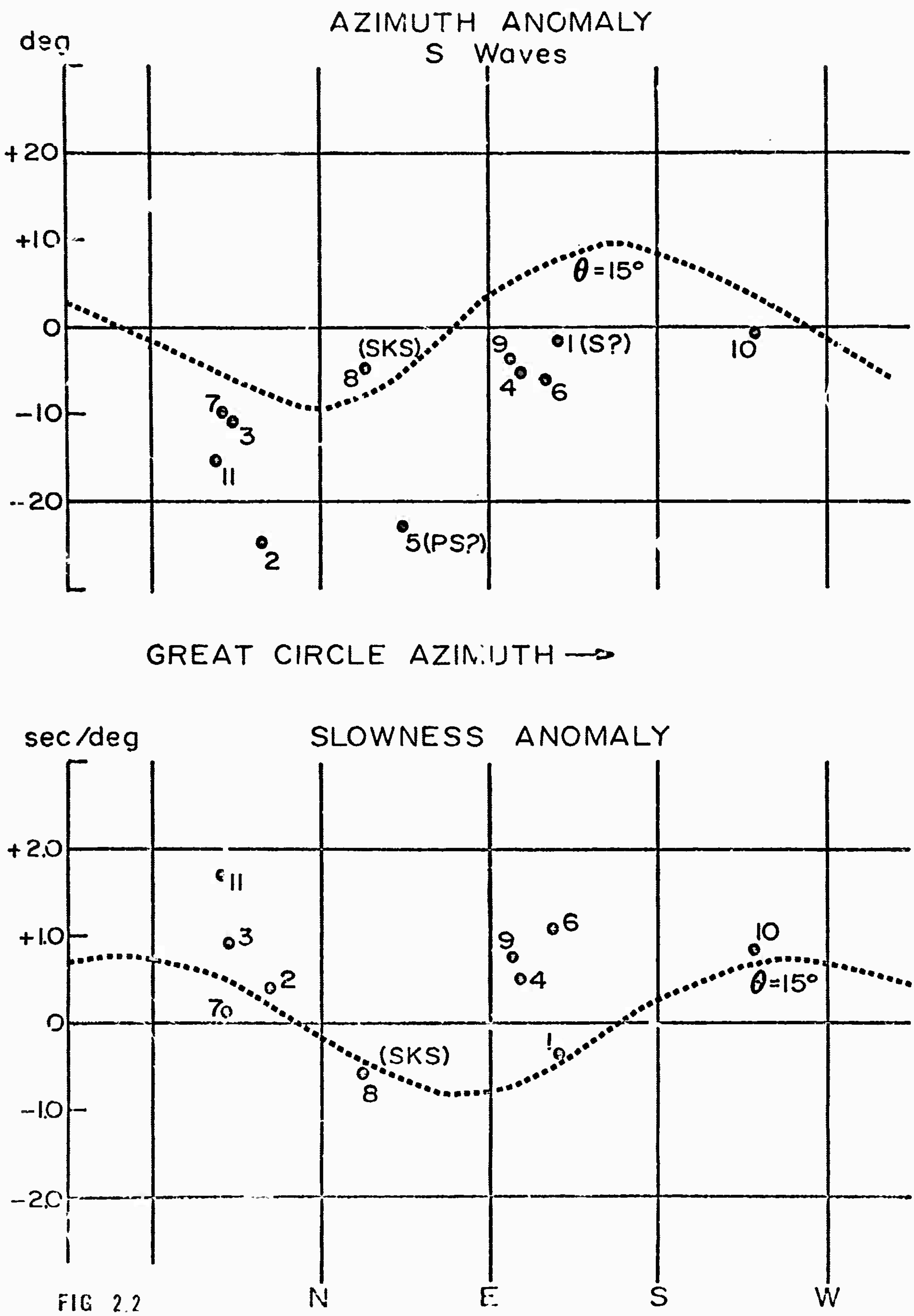

AZIMUTH ANOMALY
S Waves
deg
+20
+10
0
-10
-20
θ=15°
(SKS)
1 (S?)
5(PS?)
GREAT CIRCLE AZIMUTH
SLOWNESS ANOMALY
sec/deg
+2.0
+1.0
0
-1.0
-2.0
θ=15°
(SKS)
N
E
S
W

FIG 2.2

1) At near distances, there may be considerable ground motion being recorded at the time of arrival of S. This makes the exact instant of S arrival difficult to determine in some cases and complicates the ground motion at the time of the S arrival.

2) The SV and SH components of the shear motion behave quite differently upon reflection; thus in a study of the ground motion due to the S arrival, two horizontal components of ground motion are needed to separate SV and SH.

3) The array is located near a continental margin in a tectonically active region. The surface geology is complex.

4) Because of the proximity of the sources, the seismic wave fronts of transverse motion cannot be considered plane.

To incorporate some of these considerations into an interpretation of the observations, synthetic seismograms are being constructed at near distances due to an SH torque pulse in a layer overlying an infinite half-space. Cagniard's technique is followed and integral solutions to a step-function time variation of the source have been obtained. Once evaluated, these solutions can be convolved with an arbitrary source time function to yield the synthetic seismogram due to the assumed source. Evaluation of the integral solutions is now in progress. Certain difficulties have been met due to singularities in the integrand along the path of integration.

2.4 Earthquake Mechanism.

Research during 1967 progressed with studies of various techniques directed toward estimation of the parameters describing the earthquake source mechanism. Conventional fault plane solutions, spectral studies of evidence for rupture length and velocity and possible intensity variation along the rupture, radiation patterns and spatial distribution of earthquake sequences, as well as spectral characteristics of microearthquakes as small as magnitude -1.0 are all being considered in various facets of the mechanism research. A broad spectral range, from 0.20 to 20 cps, of seismic radiation is available for study on various recording systems now operating within the array. Fault plane solutions and dimension data from spectral characteristics have been determined for earthquakes as small as magnitude 3.8. Locally, within the micronet at SAGO, much smaller shocks are being studied.

In addition to the fault plane studies described in the section on seismicity and tectonics, the source mechanism of the main shock of the Parkfield, California earthquake of June 28, 1966 has been investigated in detail. Readings from the array were crucial in this study. Field evidence suggests typical, San Andreas, right-lateral faulting as giving rise to the Parkfield sequence of 1966. Ground surface breakage in the epicentral region strikes from about N35°W, near Cholame to the south, to N40°W, near Parkfield to the north. Additionally, records of intense ground motion recorded just after the main shock, southeastward along the fault zone from the main shock epicenter, suggest that the source of the main shock may have propagated to the southeast for some 30-40 km, at a speed of about 2.2 km/sec.

Figure 2.3 is a lower focal hemisphere equal area projection of P wave onset directions for the main shock of 0426 GMT on June 28, 1966.

Assuming the northwest plane to be the fault plane, the limiting solutions are

<u>Fault Plane</u>

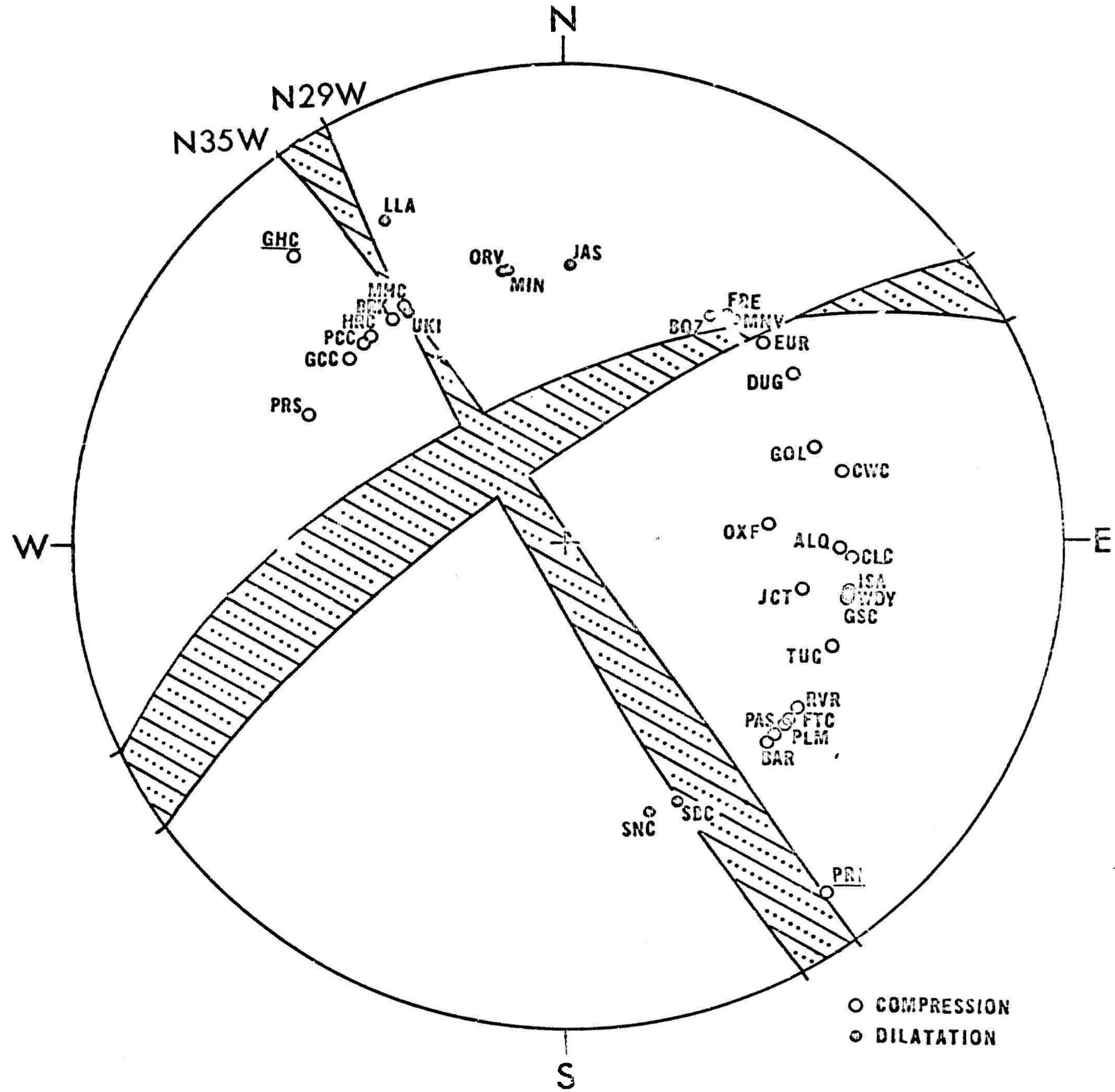
	Strike	Dip	Motion
1)	N35°W	88° NE	Right lateral 13° upward component on SW block
2)	N29°W	85° SW	" " 26° " " " " " .

The large events of 0408 June 28 (M = 5.1) and 1953 June 29 (M = 5.0) have the same radiation pattern as the main shock. First motions observed at a few key stations of the Berkeley array (PRI, PRS, and LLA) indicate that the pattern remained continuous throughout the sequence. Hypocenters are concentrated closely along the fault zone. Thus, right-lateral deformation, essentially along the strike of the San Andreas, appears to be the characteristic pattern of strain release of the Parkfield sequence.

The long-period instruments at BRK recorded a suite of well developed Love waves from a foreshock, the main shock, and three aftershocks of the Parkfield sequence. The existence of this strong horizontal transverse component of motion at BRK, nearly on a node for P motion, strongly supports a <u>double couple</u> as representative of the system of forces acting in the focal region. Because of the suggestion from field observations of propagation of the source of the main shock, the spectra of these Love waves were studied for further evidence of this propagation.

The spectra of the main shock (5.5), the largest foreshock (5.1), and three of the larger aftershocks (5.0, 4.1, and 3.8) are shown in Figure 2.4. Since all of these earthquakes were in essentially the same location with respect to BRK, and the paths to that station were identical, we normalized the spectra of the four larger events to that of the smallest, in an attempt to isolate any source effects. The normalized spectra are shown in Figure 2.5. The striking feature of these spectra is the sharp minima in the spectra of the main shock, at periods of 22.5, 9.8, and 7.6 seconds. The normalized spectra of the smaller events are relatively smooth at these periods.

If one considers the effect on the seismic spectrum due to propagation of the source away from the observer, it is found to be a modulation of the form sin x/x, where $x = w \lambda \frac{\ell}{2}$; w = angular frequency, $\lambda = \frac{1}{c} + \frac{1}{\alpha}$, c = seismic phase velocity, α = propagation velocity or fault rupture velocity and ℓ = length of propagation or fault length. Such a modulation in the spectrum introduces zeroes. In the case of constant phase velocity, these zeroes are at periods equal to a maximum time delay, and its sub-multiples. The maximum time delay is the time of the rupture propagation to the end of the fault plus the time of seismic wave propagation back to the point of initial rupture. The effect of normal seismic dispersion is to shift the higher order zeroes from exact sub-multiples of the fundamental zero toward larger periods.


N
N29W
N35W
W
E
S
LLA
GHC
ORV
MIN
JAS
MMC
BRK
HRC
PCC
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PRS
FRE
BOZ
MNV
EUR
DUG
GOL
CWC
OXF
ALQ
CLC
JCT
ISA
WDY
GSC
TUC
RVR
PAS
FTC
PLM
BAR
SNC
SDC
PRI
COMPRESSION
DILATATION

FIG 2.3

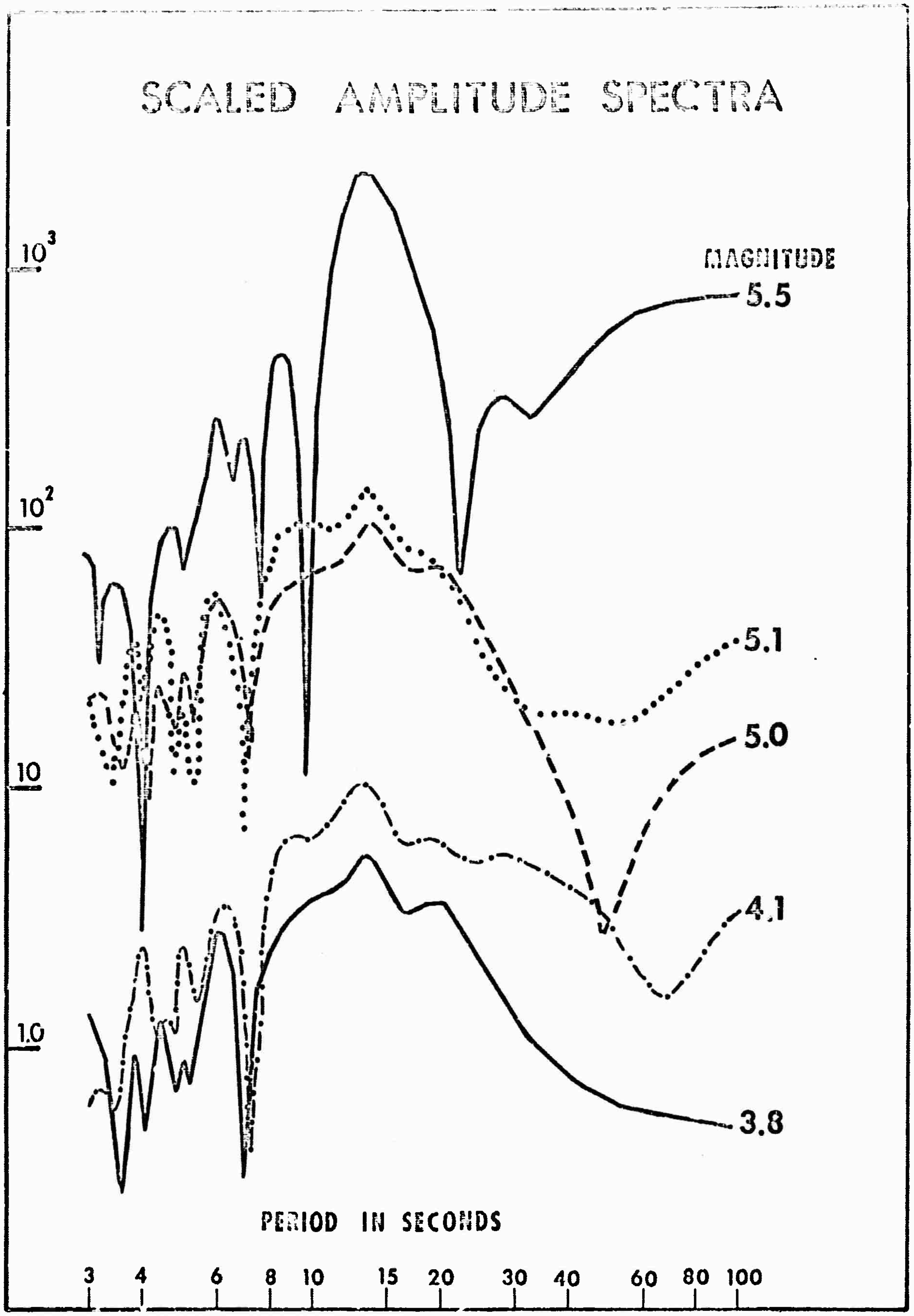
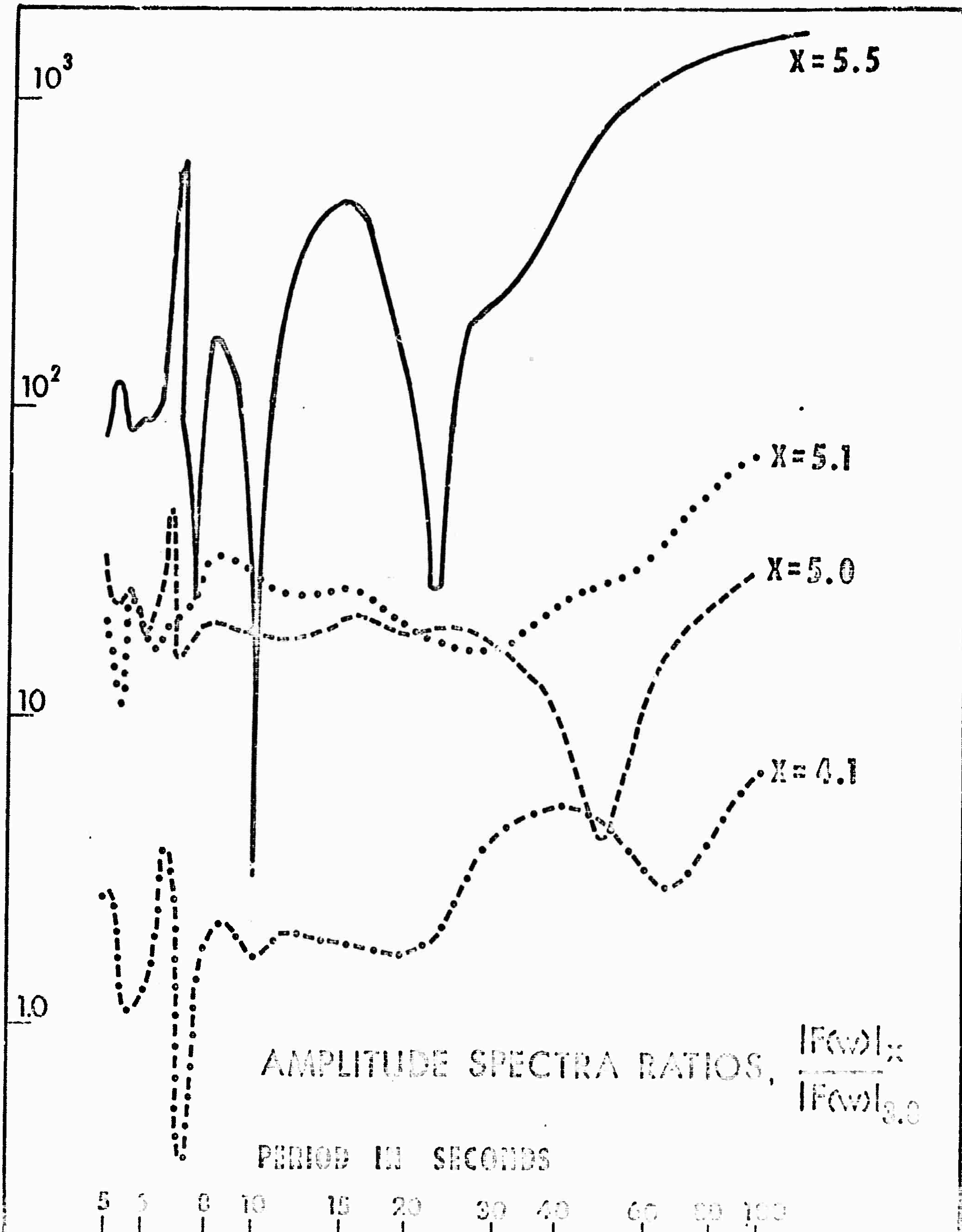

SCALED AMPLITUDE SPECTRA
10^3
10^2
10
1.0
MAGNITUDE
5.5
5.1
5.0
4.1
3.8
PERIOD IN SECONDS
3 4 6 8 10 15 20 30 40 60 80 100

FIG 2.4



X = 5.5
X = 5.1
X = 5.0
X = 4.1
10^3
10^2
10
1.0
AMPLITUDE SPECTRA RATIOS, |F(w)|x / |F(w)|3.0
PERIOD IN SECONDS
5
8
10
15
20
30
40
60
100

FIG 2.5

Numerous numerical experiments were conducted in an effort to determine the combination of rupture length and velocity which would produce the minima observed in the spectrum of the Parkfield main shock. Linear variations of the rupture velocity along the fault were also considered. A rupture velocity of 2.2 km/sec and a rupture length of about 30 km appear to give closely the modulation effect observed, although an exact fit to the observed minima was not obtained. Considered individually as the fundamental, and first and second submultiples, the observed minima at 22.[illegible], 9.8, and 7.6 seconds are consistent with rupture lengths of 31, 26, and 29 km. These lengths were computed using a rupture velocity of 2.2 km/sec.

Parkfield presents, then, a clear case where certain geometric and dynamic source parameters inferred from seismograms can be compared with field observations taken within the meizoseismal region. The fault plane solution agrees well with the trend of the observed ground breakage. The spectral differences between the main shock and smaller events may be interpreted as due to source propagation from near Parkfield, southeastwards within the San Andreas fault zone for some 30 km at a velocity of about 2.2 km/sec. These dynamic parameters are consistent with evidence of intense ground motion recorded southeast of the main shock epicenter just after the occurrence of the main shock.

This successful demonstration of the significance in observable variations in spectral content with magnitude in terms of source parameter differences is encouraging. Further work along this line is in progress directed toward extending techniques to higher frequencies and thus smaller magnitude shocks. The present configuration and instrumentation of the entire array will allow measurements to be made of spectra for earthquakes as small as magnitude -1.0.

3.0 Network Operation (January 1, 1967 to December 31, 1967).

The Berkeley network of stations (telemetered and local photographic) has continued to operate, with preventive and corrective maintenance, in a satisfactory manner. Down time for the last year has been of the order of one per cent per station. Ninety per cent of down time has been due to telephone line or Develocorder troubles. These Develocorders (Geotech model 4000) were placed in operation in 1961 and have run continuously ever since. They are now to be overhauled and rebuilt, pending delivery of new parts and updating modules on order. All records (photographic, film, Helicorder and selected events on magnetic tape) have been catalogued and are in archive storage. Table 3.1 shows magnetic tape channel assignments for the year covered by this report. Table 3.2 lists the Berkeley network as of December 31, 1967.

Network changes (in chronological order)

On January 11 and 12, 1967, a Willmore horizontal seismometer was installed at GCC and PRS in place of the Benioff vertical, and oriented N45°E. It operates with $T_o = 3$ sec, $T_g = 0.2$ sec through a modified Willmore bridge. Recording is at Berkeley on Develocorder film and magnetic tape; the Develocorder calibration is shown on Figure 3.1.

On January 13, 1967, a Willmore horizontal seismometer was installed at SAO in addition to the Benioff vertical. It was oriented N45°E and operated through a modified Willmore bridge. $T_o = 3$ sec, $T_g = 0.2$ sec; recording is at Berkeley on Develocorder film and magnetic tape. The Develocorder calibration is shown on Figure 3.1.

Table 3.1

MAGNETIC TAPE CHANNEL ASSIGNMENT

January 1 - December 31, 1967

	January 5, 1967	January 11, 1967	November 9, 1967
1	Time Code	Time Code	Time Code
2	BRK Z (SM)	BRK Z (SM)	BRK Z (SM)
3	BRK Z	BRK Z	BRK Z
4	BRK N45°W (SM)	BRK N45°W (SM)	BRK N45°W (SM)
5	BRK N45°W	BRK N45°W	BRK N45°W
6	PCC	GCC N45°E	GCC N45°E
7	Comp	Comp	Comp
8	BRK N45°E (SM)	BRK N45°E (SM)	BRK N45°E (SM)
9	BRK N45°	BRK N45°E	BRK N45°E
10	PRI	PRI	PRI
11	MHC	MHC	MHC N45°E
12	SAO	SAO N45°E	SAO N45°E
13	PRS	PRS N45°E	PRS N45°E
14	JAS	JAS	JAS

Table 3.2

SEISMOGRAPHIC STATIONS OPERATED BY OR AFFILIATED WITH THE UNIVERSITY OF CALIFORNIA

December 31, 1967

Key:

Instrument Types

A = Strong Motion Accelerometer (3-comp.)
R = Willmore
B = Benioff 100 KG
b = Benioff 14 KG
P = UED Long-Period
S = Sprengnether Long-Period
G = Geotech Long-Period
W = Wood-Anderson
L = Loucks-Omori
s = Sprengnether Short-Period
Z,N,E = Components operating, Vertical North-South, East-West
nw, ne = Components operating, N45°W, N45°E
H = 6-20 Microearthquake system
T = 15 sec Pendulum Tiltmeter

Recording Method

S = Smoked paper
P = Photographic
H = Helicorder
Hm = Helicorder telemetry monitor, sequenced daily
V = Other visible (Mary)
F = 16 mm film (Develocorder)
T = Berkeley magnetic tape
ST = SAGO magnetic tape
SC = Strip chart

Magnification

(V) = 16 mm film viewed at 20X

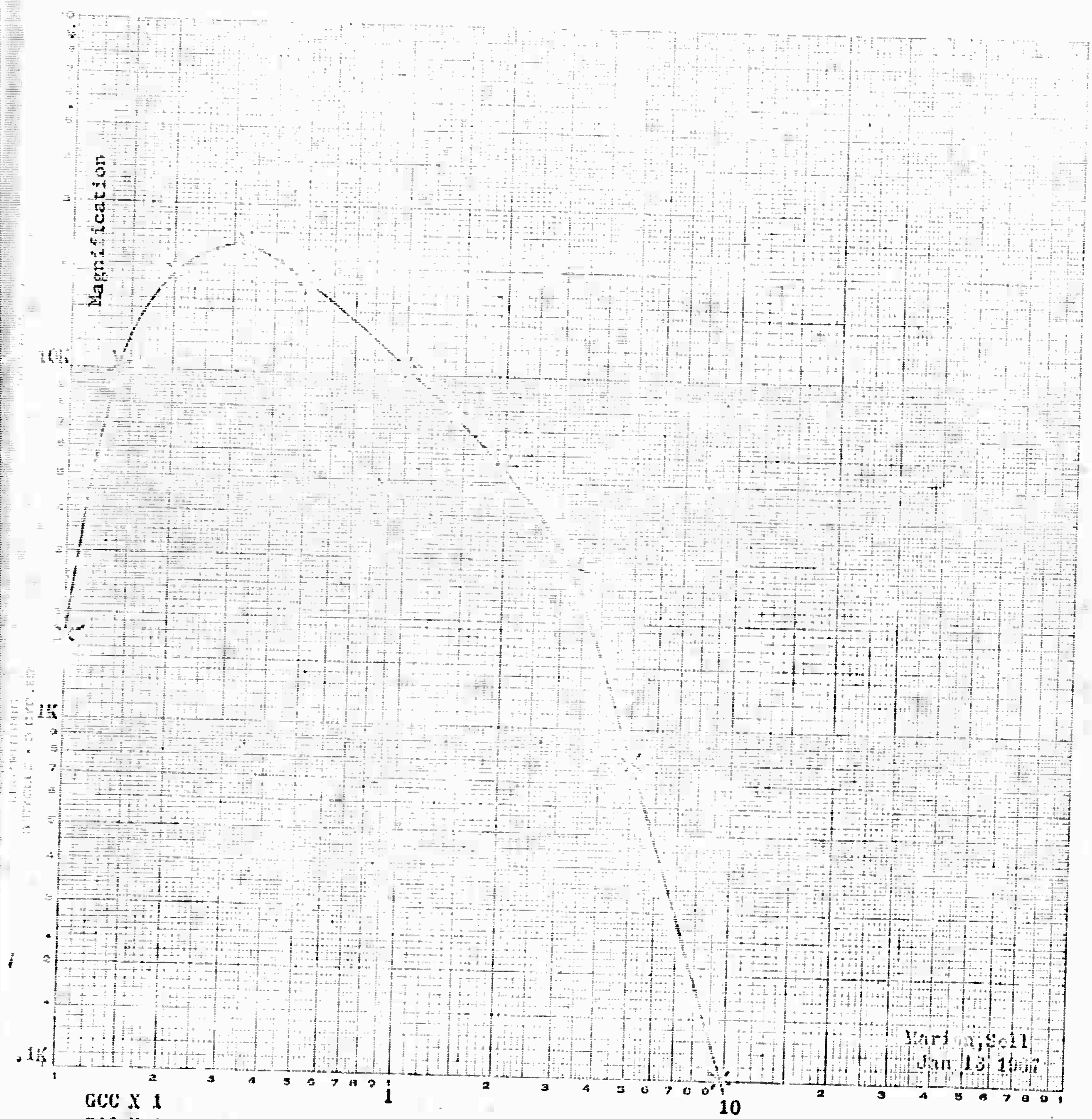
Station	Area (Calif.)	Elev. (m)	Latitude (N)	Longitude (W)	Type	T_s	T_g	Max.	1 cps	Recording Method
ARC	Arcata	59	40° 52!6 (0.877)	124° 04!5 (0.075)	bZ	1.0	0.2		5900	P
					WNE	0.8	-	2800		P
BRK	Berkeley (E.S.B.)	81	37° 52!4 (0.873)	122° 15!6 (0.260)	WNE	0.8	-	100		P
					WNE	0.8	-	4		P
					BZ	1.0	0.2		24000(V) 2400(V)	F, Hm
	(Hav.H.)				BZ	1.0	8.0	3000		V
					PZ^{nw}_{ne}	30	-	200 & 20 v/cm/sec 0.04-10 cps	-	T,H(Z)
					PZ	15	30	1000	-	H
					Pne	45	300	650 (40 sec)	-	P
BKS	Berkeley (Strawberry Canyon)	276	37° 52!6 (0.877)	122° 14!1 (0.235)	WNE	0.8	-	2800	-	P
					BZNE	1.0	0.75	35000	25000	P
					SZNE	15	100	3000 (15 sec)	-	P
CNC	Concord	36	37° 58!1 (0.968)	122° 04!3 (0.072)	BZ	1.0	0.2		26000	H
FRE	Fresno	88	36° 46!0 (0.767)	119° 47!8 (0.797)	sNE	2.0	2.0		6500(NE)	P
					GZ	1.0	.75		4000(Z)	
GCC	Granite Creek	122	37° 01!8 (0.030)	121° 59!8 (0.996)	Rne	3.0	.2		10000(V)	T,F,Hm

Station	Location: Area (Calif.)	Elev. (m)	Latitude (N)	Longitude (W)	Instruments: Type	T_s	T_g	Magnification: Max.	1 cps	Recording Method
JAS	Jamestown	450	37° 56′.8 (0.9[illegible])	120° 26′.3 (0.438)	BZNE bZ	1.0 1.0	0.75 0.2		260000 600000(V)	P T,F,H
LLA	Llanada	475	36° 37′.0 (0.617)	120° 65′.6 (0.943)	bZ	1.0	0.[illegible]		50000(V)	F,Hm
MHC	Mt. Hamilton	1282	37° 20′.5 (0.341)	121° 38′.5 (0.642)	Rne bZ WNE	3.0 1.0 0.8	0.2 0.2	160 v/cm/sec 0.4-4.0 cps 2800	 60000(V)	T F,H P
MIN	Mineral	1495	40° 20′.7 (0.345)	121° 36′.3 (0.605)	BZ WNE	1.0 0.8	0.4	 2800	75000	P P
MLC	Manzanita Lake	1800	40° 32′.2 (0.537)	121° 33′.7 (0.563)	LNE	6.0	-	250		S
ORV	Oroville	1180	39° 33′.3 (0.555)	121° 30′.0 (0.500)	BZNE GZNE	1.0 15	0.75 100	 3000	100000	P P
PCC	Pilarcitos Creek	91	37° 30′.0 (0.500)	122° 22′.9 (0.382)	bZ	1.0	0.2		50000(V)	T,F,Hm
PRI	Priest Valley	1187	36° 08′.5 (0.142)	120° 39′.9 (0.665)	bZ	1.0	0.2		70000(V) & 7000(V)	T,F,H
PRS	Paraiso Springs	363	36° 19′.9 (0.332)	121° 22′.2 (0.370)	Rne	3.0	0.2		21000(V)	T.F.Hm
SAO	S.A.G.O. 10 km SW of Hollister	230	36° 45′.9 (0.765)	121° 26′.7 (0.445)	bz Rne TNE A	1.0 3.0 15.0 -	0.2 0.2 - -		100000(V) 14000(V)	F,Hm T,F,Hm SC P
SAO	SW (William)		36° 45′.9	121° 26′.8	HZ	0.2	-	2×10^7 (V) (20 cps)		F,H,ST
SAO	East		36° 48′.4	121° 24′.4	HZ TNE A	0.2 15.0 -	- - -			ST SC 35mm film
SAO	Top		36° 46′.0	121° 26′.7	3-Component Magnetometer					SC
SAO	SE		36° 46′.3	121° 25′.2	HZ	0.2	-			ST
SAO	NW		36° 47′.4	121° 27′.0	HZ	0.2	-			ST

[illegible]

RECORDED ON DEVELOCORDER

[illegible]



GCC X 1
SAO X 1.4
PHS X 2.1

Period in sec.

Fig. 3.1

On March 29, 1967, a 14.7 Kg Benioff and galvanometer were installed at Fresno in place of the 2 sec Sprengnether, $T_o = 1$ sec, $T_g = 0.36$ sec, which had been calibrated in 1963 by J. Eaton. The calibration of the new instrument is shown on Figure 3.2.

On August 22, 1967, the Fresno galvanometer was changed from a free period of 0.36 sec to one of 0.75 sec to improve signal-to-noise characteristics at this station. The new calibration is shown in Figure 3.3.

On November 28, 1967, a Willmore horizontal seismometer was installed at MHC in addition to the Benioff vertical. The orientation is N45°E. As with the other similar instruments, it operates with $T_o = 3$ sec, $T_g = 0.2$ sec through a modified Willmore bridge. The signal is recorded at Berkeley on magnetic tape only. Figure 3.4 shows the calibration for this component.

Field Operations with Mobile Van Recording Unit

Date	Location	Latitude (North)	Longitude (West)	Event
May 19, 1967	Harris Ranch	36° 46!3	121° 24!8	NTS explosion.
May 23, 1967	Indart Ranch	36° 46!2	121° 15!5	NTS explosion (requested by USGS).
June 2 and 3, 1967	San Clemente Dam	36° 26!7	121° 42!5	USGS blast (Coast Ranges).
June 5 to 16, 1967	Conlan Ranch	37° 05!3	121° 44!9	USGS blast (Coast Ranges).
June 25, 1967	SAGO East	36° 48!4	121° 24!4	USGS blast (Coast Ranges).
Sept. 8, 1967	Conlan Ranch	37° 05!3	121° 44!9	Earthquake, Corralitos area, magnitude 4.7.
Sept. 28, 1967	Coyote Fire Station	37° 05'	121° 29'	Earthquake, Anderson Dam, magnitude 5.
Dec. 18, 1967	Uvas Dam	37° 04!2	121° 42'	Earthquake, Watsonville, magnitude 5-1/4.

FRESNO

Magnification curve for vertical system installed March 29, 1967

14.7 Kg Benioff at 1 cps and 0.36 sec. galvanometer

curve based on data obtained with 36 db of attenuation

placed in operation March 30, 1967 at 24 db

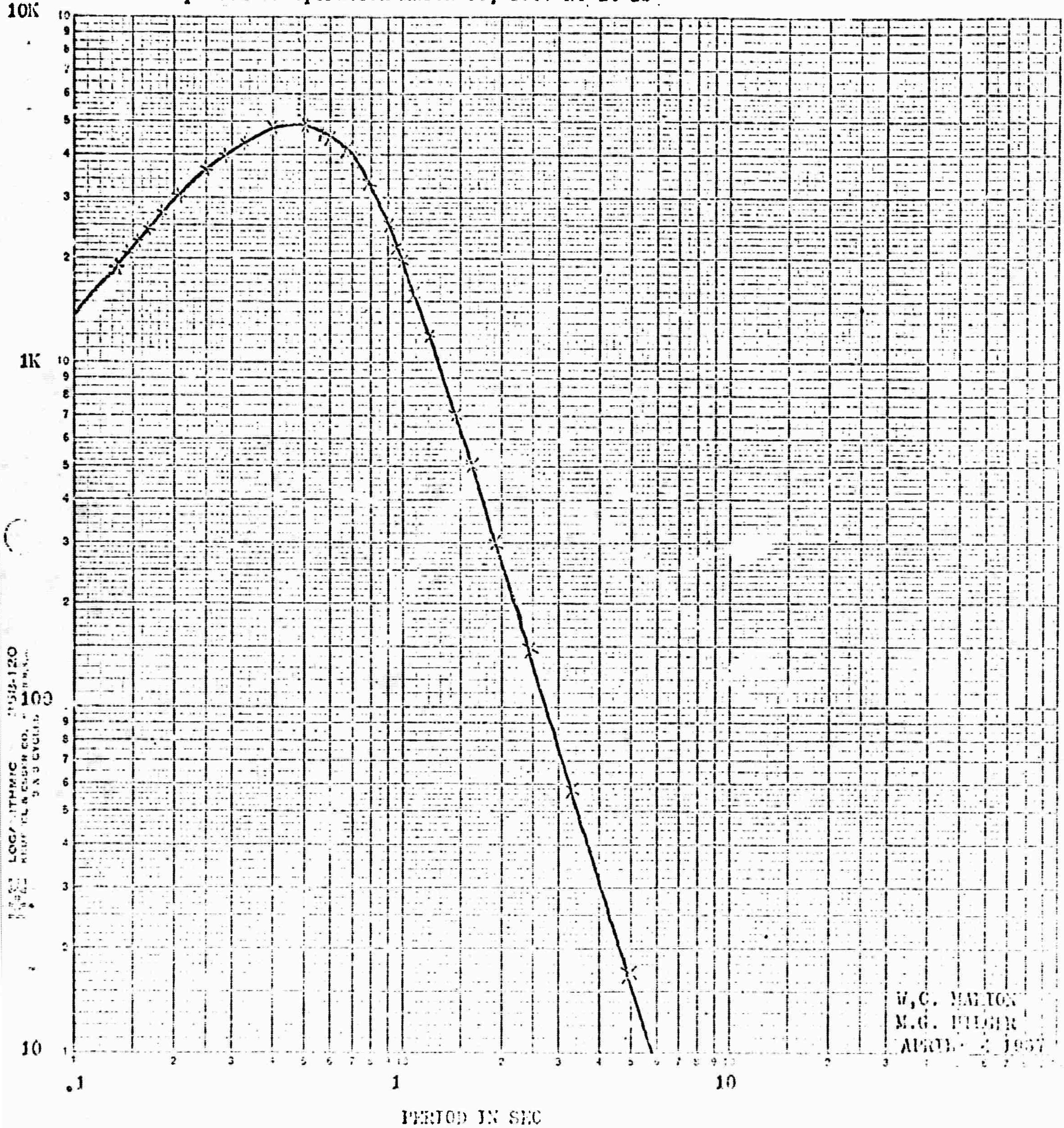


Fig. 3.2

FRESNO

14.7 Kg. Vertical Benioff - .75 sec. galvanometer

attenuator at 18 db for calibration

operating at 12 db Aug. 22, 1967

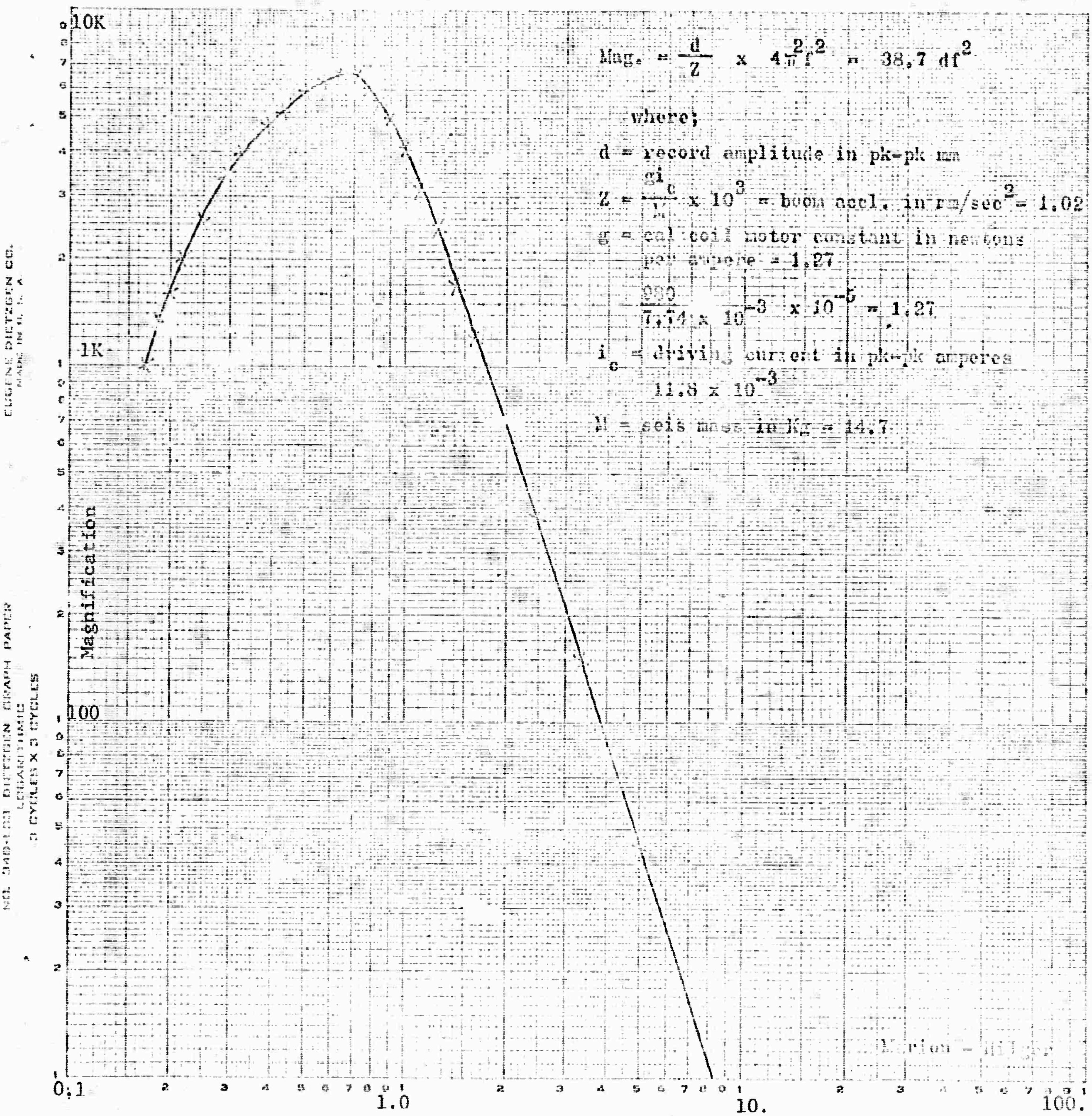


Fig. 3.3

MT. HAMILTON

MAGNIFICATION CURVE

WILLMORE HORIZONTAL SEISMOMETER

N45° E T_o = 3 SEC. T_g = .2 SEC.

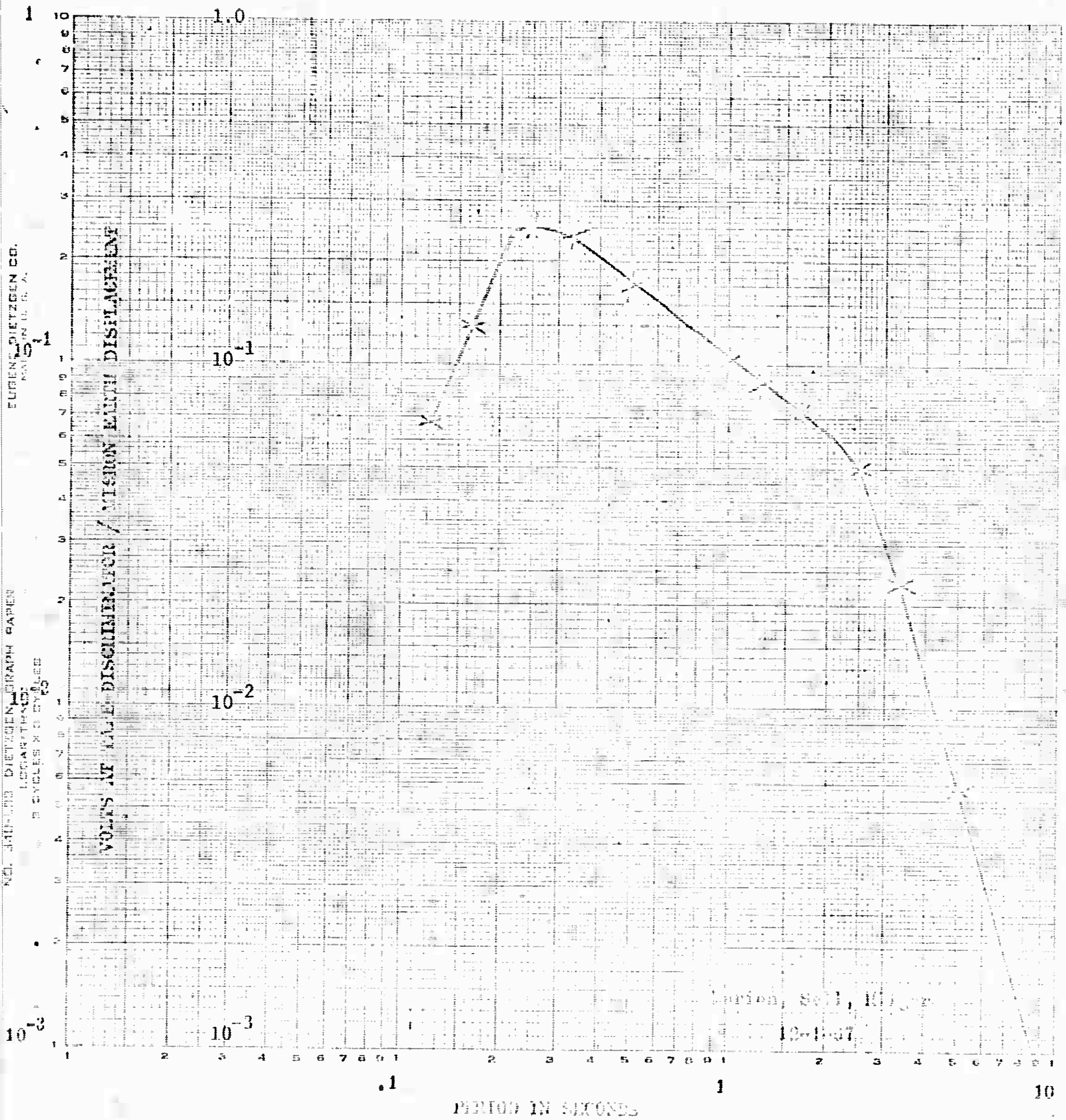


FIG. 3.4

4. Research Papers Acknowledging Contract Support.

The list which follows contains those papers which were published in 1967 or are in the press and which depended wholly or partly on observations from the UC, Berkeley array.

Bolt, B.A. and T.V. McEvilly (1968)"Earth Structure and Focal Mechanism: Evidence from the Berkeley Array", Comptes Rendus, Bur. Cent. Seis., (in the press).

Bolt, B.A., C. Lomnitz, and T.V. McEvilly (1968) "Seismological Evidence on the Tectonics of Central and Northern California and the Mendocino Escarpment", Bull. Seism. Soc. Am., (in the press).

Filson, John and T.V. McEvilly (1967) "Love Wave Spectra and the Mechanism of the 1966 Parkfield Sequence", Bull. Seism. Soc. Am., 57, 1245-1248.

Lomnitz, C. and B.A. Bolt (1967) "Evidence on Crustal Structure in California from the Chase V Explosion and the Chico Earthquake of May 24, 1966", Bull. Seism. Soc. Am., 57, 1093-1114.

McEvilly, T.V. and K.B. Casaday (1967) "The Earthquake Sequence of September 1965 near Antioch, California", Bull. Seism. Soc. Am., 57, 113-124.

McEvilly, T.V., W.H. Bakun and K.B. Casaday (1967) "The Parkfield Earthquakes of 1966", Bull. Seism. Soc. Am., 57, 1221-1244.

Rodgers, P.W. (1967) "Parametric Phenomena as Applied to Vibration Isolators and Mechanical Amplifiers", J. Sound Vib., 5 (3) 489-498.

5. Expenditures to Date (December 31, 1967).

General Assistance	$14,392
Supplies and Expense	25,923
Equipment and Facilities	4,554
Total	$44,869